# Accelerated Thermal and Mechanical Testing of CSP Assemblies

Reza. Ghaffarian, Ph.D.
Jet Propulsion Laboratory, California Institute of Technology , Pasadena, CA
Reza.Ghaffrian@JPL.NASA.Gov, (818) 354-2059

## ABSTRACT

Chip Scale Packages (CSP) are now widely used for many electronic applications including portable and telecommunication products. The CSP definition has evolved as the technology has matured and refer to those packages with a pitch of 0.8 mm and lower. Packages with fine pitches, especially those with less than 0.8 mm, and high I/Os may require the use of microvia printed wiring board (PWB) which is costly and they may perform poorly when they are assembled onto boards. A test vehicle (TV-1) with eleven package types and pitches was built and tested by the JPL MicrotypeBGA Consortium during 1997 to 1999. Lessons learned by the team were published as a guidelines document for industry use[1].

The finer pitch CSP packages which recently become available were included in the next test vehicle of the JPL CSP Consortium[2]. The Consortium team jointly concentrated their efforts on building the second test vehicle (TV-2) with fifteen (15) packages of low to high I/O counts (48 to 784) and pitches of 0.5 mm to 1.27 mm. In addition to the TV-2 test vehicle, other test vehicles were designed and built by individual team members to meet their needs. At least one common package was included as control in each of these test vehicles in order to be able to compare the environmental test results and understand the effects of PWB build and manufacturing variables.

One test vehicle was designed and assembled by Hughes Network Systems using their internal resources and is identified as TV-H. This paper presents the most recent thermal cycling test results to 900 cycles which are currently being performed under -55 to 125°C conditions for packages with various die sizes. Mechanical fatigue test results for the 280 I/O count packages under various deflections with and without local heating are also presented.

## CSP TEST MATRIX

**Test Vehicle Package I/O /PWB**

The TV-H had eight packages ranging from 48 to 280 I/Os with pitches of 0.8 mm as shown in Figure 1. The PWB had four layers with the two resin coated copper (RCC) layers and an FR-4 core (1+2+1) having a total thickness of 0.43 mm. Microvia technology was used. The pad had a 0.1 mm (4 mil) microvia hole at the center of pad. A non-solder-mask-design (NSMD) pad with a diameter of 0.3 mm and 0.05 mm clearance was used. The surface finish of the PWB was Ni/Au immersion with about 2-8 micro inch of gold over 100-200 micro inch Ni. No clean solder paste for assembly was applied with a 5 mm thickness laser cut stencil. The test vehicle was 11.9 cm by 4.6 cm (4.75″ by 1.85″) with one connector attached for continuous thermal cycling monitoring. The width of test vehicle was cut into 1" for the three point bend fatigue testing.

**280 I/O Package/Test Vehicle Features**

Figure 1 shows a full populated test vehicle (TV-H) with two sites for the 280 I/O fine pitch ball grid array (U4 and U2 sites). All packages were daisy-chained, and they were divided into several internal chain patterns. The daisy chain pattern on the PWB completes the chain loop into the package through solder joints. Several probing pads connected to daisy chain loops were added for failure site diagnostic testing. The package and PWB daisy chains for the 280 I/O package is shown at the bottom of Figures 2. All locations sites including U4 and U2 sites were populated for the thermal cycling assembly testing. Only the U4 location was populated for mechanical cycling testing. All packages were prebaked at 125°C for 2 ½ hours prior to assembly.

## TEST CONDITIONS

### Thermal Cycling test

Thermal cycling was performed in the range of –55°C to 125°C. The heating and cooling rates were 2° to 5°C/min with a dwell at maximum temperature of more than 10 minutes and a shorter dwell time duration at the minimum temperature. Each cycle lasted 159 minutes. The test vehicles were monitored continuously during the thermal cycles for electrical interruptions and opens.

### Mechanical Cycling Test

Mechanical cycling test was performed using a three point bending test set up as shown schematically in Figure 2. This test vehicle coupon had one package at its center. The center of package along the PWB was set on a stationary ram with 3.13 mm (1/8") radius. The coupon was in contact along its edges with two moving bars, spaced at 80 mm apart each having a 3.13 mm (1/8") radius. These two bars pushed the coupons down onto the stationary ram with specified maximum deflections for mechanical cycling. To determine the maximum deflection of assembly under static condition, a test coupon was tested to failure by continuously increasing deflection. Failure was automatically detected by application of current to the daisy chain with 3.2 ohm resistance to achieve a four (4) volt output. Monitoring was accomplished by interfacing a PC into the output signal from the mechanical testing system and recording data. When the daisy chain become open, the output voltage from the system increased to 4.16 volts. Voltage output and deflection levels were continuously recorded in a data base for retrieval and data analysis.

The first three test results were inconsistent and they failed unexpectedly at very low values. Two observations were made: (1) the test coupon was slightly moved during cycling form its zero deflection state, and (2) the application of high current into the daisy chain introduced heat into the package. The first observation was corrected by using a double sided tape to secure the coupon to the bars in order to minimize the movement of the coupon. The second observation corrected for by using current as variable. A set of test coupons were tested under current condition thereby further accelerated cycles-to-failure relative to a no-current condition. To know the effects of current on package temperature, the package surface temperature was monitored by thermocouple before the start and during mechanical cycling. The temperature rises were in the range of 95°C-105°C. When no current was applied, the daisy chain resistance was monitored using a multimeter. The first increase in resistance (considered initiation of failure) was reported. Test was continued until complete daisy chain open condition and this value was also recorded.

## TEST RESULTS

### Thermal Cycling Results

Only a limited number of test vehicles were subjected to accelerated thermal cycling condition (-55 to 125°C). The most recent thermal cycle test results to 500 cycles for these are presented in a recent publication [2]. Cycles-to-failure (CTF) for other packages and under other thermal conditions are being gathered and will be analyzed and presented in the future.Figure 4 shows cycles to first failures for the 280 I/O FPBGA with 3 die sizes. The 280 I/O package with an 11.8 mm die in 16 mm packages failed in the range of 303 to 824 cycles. For packages with 9.5 mm die, only two out of the 10 assemblies failed at 690 and 836 cycles when they are subjected to a total of 900 thermal cycles.

### Mechanical Cycling Results

Twenty test coupons were used for accelerated mechanical cycling testing under deflection levels from 0.125 mm to 1.875 mm (0.005" to 0.075"). The maximum cycling deflection value represents approximately 30% of maximum deflection under static test. MCTF for assemblies with various die sizes for single and combination of two to three deflection levels to 300,000 cycles are listed in Table 1.

Conditions listed are failure under static deflection and failure under mechanical cycling with and without application of 4 volts to the package/PWB daisy (chain resistance 3.2 Ohms). The load deflection under static condition was determined and found to have a linear relationship, i.e. as load increased the deflection increased. The maximum deflection prior to failure was 5.65 mm (0.226") under 4 volt condition. This value is expected to be higher if no current were applied to the daisy chain during testing.

To achieve accelerated failure to less than a day under 5 Hz cycling frequency (10,000 cycles for every 33 minutes), damage levels were accumulated under increasing level of deflection. Deflection levels were increased when assemblies survived 10,000 cycles under one level of deflection. Further acceleration was achieved by application of current to the daisy chain resistance of package/PWB. Data presented in Table 1 clearly indicates that assemblies failed under maximum combined deflection of 1.25 mm (.050") for a 4 volt condition. The maximum deflection increased to 1.875 mm (.075") when no current was applied. If no damage accumulation technique is used then assemblies under deflection of .625 mm (0.025") with and without current failed at 104,000 and more than 400,000 cycles (300,000 cycles plus 87,000 at 0.050"), respectively. Note the MCTF reduction when assemblies were subjected to 150°C for only 20 minutes. This temperature and time represent cure of a reworkable underfill.

### Failure Mechanisms

Assemblies are currently being subjected to scanning electron microscopy, cross-sectioning, and pull test to determine failure mechanisms due to various accelerated mechanical cycling schemes. However, several observations were made during mechanical cycling when assemblies start to show signs of failure. One aspect was included in Table 1 by listing the MCTF range from the start of daisy chain voltage/resistance increase to complete daisy chain open. In general, increase in resistance or voltage was slow and sometimes it required thousands of additional cycles before a complete daisy chain open occurred under loading (deflection). Failure under load was not permanent for most cases, especially for no voltage condition. Daisy chains showed increase in resistance after removal of load, but did not show a complete open. Under current application conditions, sometimes complete failure occurred under both load and no load conditions.

## DISCUSSION

New applications of advanced electronic packaging, including chip scale package in consumer portable products, brought about new environmental requirements not seen in their previous generation of relatively benign office applications. The on/off cycles introduce failure of solder joints due to thermal mismatch of package and PWB. Solder joint integrity is critical since the joints carry both mechanical and electrical load. Failure of solder joints due to CTE mismatch has commonly characterized using a dummy package daisy chained through solder joints and the PWB by monitoring their failure under temperature cycling. Use of power cycling, i.e. heating solder locally by imbedding resistance inside of the package, is now are being considered as an alternative since it provides higher reliability results much needed for miniature packages.

In addition to on/off cycles, electronics in portable products are also required to be robust under mechanical conditions, e.g. robustness to repeated mechanical cycling due to key punching and to shock due to dropping or bending due to sitting on product. The mechanical requirement are not new for high reliability application environments including automotive, military, and aerospace. Conventional leaded SMT packages have been shown to be robust. Unfortunately, both the use of rigid balls instead of flexible lead and reduction of the interconnect area for most CSPs due to reduction in package size have negative effects on their environmental robustness. Accelerated thermal and mechanical testing are required to screen for different designs and also to determine robustness of CSPs in order to meet the increasing demand for time to market shrinkage for consumer products and effective use of these products for high reliability applications.

Mechanical cycling tests, if they provide the same trends as thermal cycling, could be a very effective acceleration technique. The investigation performed here was aimed at characterizing behavior of CSPs under mechanical cycling conditions and to determine if techniques can be developed to determine trends that are being established under thermal cycling conditions. One key parameter that affects thermal cycles to failure is the die size in a CSP. Thermal cycling of packages with various die sizes clearly indicated the criticality of die size and its effects on solder joint reliability. With limited tests performed, it appears that there is a possibility that such a trend can be established by mechanical cycling.

Mechanical tests with no local package heating will significantly overestimate the life of solder joints. Local heating will accelerate life testing and provide a better application representative. Very promising accelerated test results under mechanical cycling was found for those assemblies exposed to isothermal aging at 150°C for 20 minutes. These assemblies clearly showed much lower mechanical cycles to failure and the trend was apparent. Further work is required to determine if this accelerated technique could be used to screen for a variety of manufacturing defect and possibly, in conjunction with limited thermal testing, to project life for intended applications.

## CONCLUSIONS

These conclusions are based on results limited to assembly failure to 900 thermal cycles in the range of -55°C to 125°C and a limited number of mechanical cycling tests to failure.

- Cycles-to-failures for the fine pitch ball grid array (FPBGA) with 0.8 mm pitch were in the range of 300 to 800 cycles. These are significantly lower than their BGA counterparts with 1.27 mm which they failed higher than 1,000 cycles[3].
- The FPBGA failed at 5.7 mm maximum deflection under static bending load. It survived more than 400,000 mechanical cycles to maximum deflection of 0.625 mm (0.025"). This value decreased to about 100,000 cycles when packages were locally heated.
- The trend on the effects of die size, when sizes were far apart, could be possibly detected by the use of accelerated mechanical cycling and local heating of the package possibly due to heating and rigidity differences in loading. Accelerated mechanical testing detected the degradation effect of assemblies subjected to isothermal aging at 150°C for 20 minutes. Thus, such tests may be effective in screening for manufacturing defects, severe degradation due to environmental exposure, and mechanical robustness for application.

## ACKNOWLEDGEMENTS

The portion of research described in this publication is being carried out ~~by~~ at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

The JPL author would like to acknowledge the in-kind contributions and cooperative efforts of the JPL CSP Consortium. Special thanks to A. Arreola, T. Hills, JPL; M., Lam, D., Strudler, S., Umdekar, Hughes Network Systems (HNS), and package suppliers and other team members who have made contributions to the progress of this program.


## REFERENCES


1. Ghaffarian, R., "*Chip Scale Packaging Guidelines*" distributed by Interconnection Technology Research Institute, http://www.ITIR.org, (512) 833-9930
2. Ghaffarian, R., Nelson, G, Cooper, M., Lam, D., Strudler, S., Umdekar, A., Selk, K., Bjorndahl, B., Duprey, R., *"Thermal Cycling Test Results of CSP and RF Package Assemblies"*, The Proceedings of Surface Mount International, Chicago, Sept. 25-28, 2000
3. Ghaffarian, R., "*Ball Grid Array Guidelines*" distributed by Interconnection Technology Research Institute, http://www.ITIR.org, (512) 833-9930


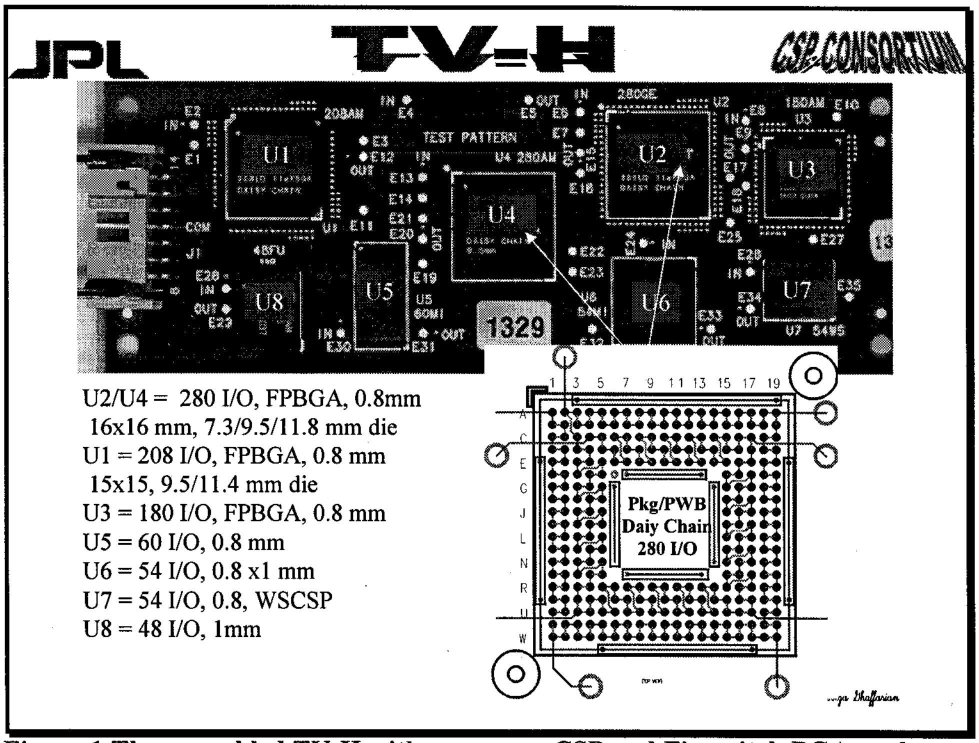


**Figure 1 The assembled TV-H with numerous CSP and Fine pitch BGA packages. The package/PWB daisy chain for the 280 I/O FPBGA is shown on the bottom right.**

**Table 1 Static and mechanical cycles-to-failure for the 280 I/O fine pitch BGA with three die sizes under various cycling conditions**

| ID | Voltage (Ohm) | Die Size (mm) | 0.025" (0.625 mm) Deflection | 0.050" (0.125 mm) Deflection | 0.075" (1.875 mm) Deflection | Comments |
|---|---|---|---|---|---|---|
| 1A | N/A | 11.8 | N/A | N/A | N/A | Static, max. deflection 5.65 mm (0.226") |
| 3C | N/A | 9.5 | 300,000 | 86,887 | N/A | Low deflection, high cycles |
| 3A | N/A | 11.8 | N/A | 10.000 | 6,470 | 6,470-7,691 cycles |
| 4B | N/A | 9.5 | 10,000 | 10.000 | 6,384 | 6,384-8,595 cycles |
| 5B | N/A | 7.3 | N/A | 10,000 | 8,450 | 8,450-10,204 cycles |
| 2C | N/A | 11.8 | N/A | 10,000 | 900 | 900-1490 cycles, **Age at 150°C, 20 min.** |
| 2D | N/A | 11.8 | N/A | 10,000 | 2,984 | 2,984-3,109, **Age at 150°C, 20 min.** |
| | | | | | | |
| 3B | 4 (3.2) | 11.8 | 104,361 | N/A | N/A | One deflection only |
| 1D | 4 (3.2) | 11.8 | 10,000 | 2,764 | N/A | 2,764-2,764 cycles |
| 4A | 4 (3.2) | 9.5 | 10,000 | 1,460 | N/A | 1,460-1865 cycles, 10,000 @ .005" |
| 5A | 4 (3.3) | 7.3 | 10,000 | 2,846 | N/A | 2,846-3,175 cycles |